Forecasting Air Quality

An issue for ~~the future~~ NOW

The purpose of this document is to outline a project to address air quality forecasting as part of NOAA's strategic goal for environmental prediction. At ARL-led meetings of NOAA mesoscale atmospheric modelers in May 1996 and October 1997, it was concluded that work toward prediction of air quality could be used as a possible early focus for a cooperative effort between atmospheric modelers and chemists. Since then, the need for air quality forecasting has become apparent in several ways – such as tourism in the Great Smokies National Park, easing energy production concerns in California, and warning susceptible members of the population in residential and employment areas.

The overall activity will draw on the skills of several NOAA Research laboratories. Here, the focus is on what ARL plans to contribute. For more than a decade, a well-documented goal of ARL science has been to institutionalize air quality forecasting within NOAA. In collaboration with partners in other laboratories and in other countries[1], ARL scientists are ready to embark.

Summary. NOAA capabilities have reached the point where we can answer many of the air quality forecasting questions that society is now asking. Moreover, the mesoscale model now being constructed to provide the foundation for weather research and forecasting (http://www.wrf-model.org; the WRF model) is designed to contain the capability for coupling air chemistry considerations with meteorology. The opportunity exists to exploit the capabilities of the WRF model, by including in it a capability not only to provide guidance on air quality but also to permit explicit consideration of the ways in which air quality affects the weather. In essence, there are two major pathways by which air quality affects weather. First, atmospheric aerosols affect the surface radiation balance, hence influencing the energy driving atmospheric circulations. The models need to take this into account. Second, the same aerosols affect cloud processes; hence forecasting cloud cover and precipitation will necessarily require information on airborne particles.

Independently of the requirement for air quality considerations to improve the accuracy of weather forecasts, there is a growing need for the provision of uniform and strongly based guidance to the public, industry, and agriculture regarding the air quality conditions likely to arise in the future. Mesoscale models (of which the WRF is the preferred model of the future) already have the grid sizes, data assimilation methodologies, and remote-sensing data acquisition methods that are required to provide air quality forecasts. At the same time, there is a strident demand for better air quality forecasts for areas where people work and live. It is proposed that NOAA step forward to accept its forecasting mandate and construct a coherent air quality prediction program out of the pieces now operating independently in the various OAR laboratories, and in conjunction with programs at NCEP.

It is not proposed that NOAA compete with the existing providers of air quality forecasts. These service providers (mainly private organizations and academic institutions) operate using air chemistry routines that are driven by meteorological forecasts already derived from NOAA. The WRF model will permit, in concept, the coupling of meteorology and air chemistry. A fully coupled modeling capability is feasible, in which the meteorology affects the chemistry and *vice versa*. This two-way coupling is necessary to reflect reality. The scales associated with the coupling are larger than those normally addressed in local air quality forecasting programs. They are suitable for inclusion in the WRF. By including them, the products provided by NOAA

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[1] Specifically, Australia, where the Minister for Environmental Affairs recently announced that Australia will have a nationwide air quality forecasting system in five years. Canada (among other countries) is engaged in similar developments.

would then include the provision of air quality guidance for those who specialize in tailoring air quality forecasts for local clients.

It is proposed that the NOAA organizations working on the science necessary to implement two-way coupling of air chemistry and meteorology in the WRF model join forces to generate a coherent and organized program leading to implementation of a demonstration of air quality predictions for the northeastern USA by 2005. It is further proposed that this work be conducted as an adjunct to the weather research program of NOAA, making full use of the enhanced observation and modeling capability offered by the larger weather-related activity.

The scales of predictions.

There are three distinctly different applications of NOAA's air quality expertise.

- Assessments – looking backwards at past events. In applications when there is need to evaluate past situations, there is an opportunity to take time, to use the best tools available, and to do the job as well as we can. The models that are then used can afford to be complex, and the science in them can be complete. A major driving consideration is the need for the answers to be defensible and objective. NOAA scientists are a valued resource in such endeavors, because of their renowned objectivity and independence.

    In this case, the main clients for NOAA expertise are in other agencies. In the past, the work has been dominated by requirements of the Environmental Protection Agency, the Department of Defense, the Department of Energy, etc.

- Projections – for policy and scenario development, and for guidance of seasonal and year-to year planning. Once again, there is the luxury of being able to use advanced models, and to exploit the best scientific understanding currently available. NOAA scientists are well regarded in these situations, for the same reasons as above -- objectivity, independence, and quality.

    In this application the clients are mainly other agencies who rely on NOAA research for high quality information to guide regulations and policy.

    Reality fix: Ozone accounts for about 90% of the pollution-induced crop yield losses in the US. Which strain of soybeans the farmer chooses to use (for example) should be influenced by a seasonal prediction of likely ozone levels. Selection of which pesticide to use might also be a critical consideration. The potential savings to farmers are estimated to be of the order of tens of millions of dollars for the state of Tennessee alone!

- Forecast guidance – to protect the population and the environment. This corresponds to NOAA's classical role, in which we provide information (warnings) related to the comfort, safety and health of people, and to the state of the environment in which they reside and on which they rely.

    In this instance, there are several distinctions that need to be made.

    Guidance for short-term air quality forecasting. Human health remains a dominating consideration. Some cities are already forecasting air quality, to help protect sensitive people and to help influence the automotive exhaust source term. In practice, these efforts have been a mixed success, largely because the models required must necessarily combine high quality meteorological with advanced air chemical capabilities. The key issues in forecasting local exposure are knowing the source term and getting the wind direction right. What is needed is a modeling capability that can simulate atmospheric behavior on the spatial scales of relevance, taking the processes affecting air quality into account.

    It is not a NOAA role to provide final products for use by every local authority. Instead, it is the NOAA strategy to provide (a) a high-quality regional picture on which local authorities can impose their own local situations, and (b) the scientific understanding

necessary for these local augmentations to be successful. In this picture, local authorities and commercial vendors would provide a "value-added" service, using the NOAA products as a foundation.

The health of the environment is also an important consideration. For example, warnings of ecological events like algal blooms are feasible, and will require prediction of atmospheric deposition. This prediction would be a necessary side benefit of the air quality model now advocated.

Guidance for emergency response – provision of forecasts "on demand." NOAA already provides the guidance desired by emergency response managers in the event of releases of hazardous materials into the atmosphere, from all sources (natural and otherwise). At this time, the guidance is provided through use of dispersion routines driven by the best available forecast meteorology. In the future, such dispersion calculations will be embedded in the mesoscale models used for research and forecasting. It is then necessary to add considerations of air chemistry to the dispersion routines, so as to permit specific attention to be given to emergencies "de jour."

Why NOAA? Among the themes that underpin NOAA's identity and its institutional strategic thinking are the concepts of prediction, stewardship, and the total environment. Air quality is an issue that has been central to NOAA's thinking for decades. We have a long history of successes, starting with the prediction of exposure following emissions of harmful materials and ending up with scenario assessments to help guide policy and regulators. In parallel with these concerns, there are newly emerging worries about the need to forecast occasions when human health might be threatened. NOAA has not ducked the issue of air quality prediction in the past. Now, it is timely for NOAA to step forward once more, to guide the science necessary to protect human health and our environment into the next century and beyond.

Why Now? The immediate answer is – Because the science is now ready to be exploited and society is asking for the products. Population continues to grow and age, without signs yet of any leveling off. People are migrating to the coasts in increasing numbers, where the total environment is already stressed. The population pressures are most severe in precisely those areas of the nation where the environment is now most at risk. Not only are people aggravating an already severe environmental problem, but the pollution produced by society is adding to an already offensive regional pollution background. Sensitive people are being increasingly threatened. It is the NOAA mission to provide forecasts to protect people, property, and the environment. Our organizational constituency is asking for NOAA to step forward and provide the guidance needed by public officials and the private sector to improve the quality of their air pollution and related public protection products.

The overall environmental problems will change as time progresses and as new regulations and controls are imposed. There are bound to be surprises, and society must be prepared for them. Water and air quality are key factors determining the sustainability of population centers; both need to be preserved. Both long-term trends and short-term episodic exposures need to be addressed, the former primarily because of the total environmental change that is feared, and the latter to protect people from severe health risk and to protect elements of the stressed environment from being pushed "over the edge." The multi-media aspects of this complicated issue are uniquely resident within NOAA. This multi-media association, however, is not a focus of this particular document.

An over-riding fear is that we cannot foresee the problems of the future. Air pollution concerns started with fears related to airborne particulate matter and gaseous sulfur dioxide. We have progressed beyond these issues to modern concerns about ozone, inhalable particulates, and visibility, and we are looking ahead to worries about mercury, persistent organics, and endocrine disruptors. The acid rain debate underlined the harsh reality that the needs of society are not satisfied by a narrow focus on a single pollutant alone; the issue has subsequently been shown to be as much associated with nitrogen as with the sulfur that controlled the acid rain issue of the 1980s. The environment (including its human subset) is increasingly stressed, and is increasingly vulnerable to any change in the pattern of these stressors. We do not know which of many air pollutants will be the one that will cause the most deaths in the future. Society needs the tools to forecast changes in air quality, as well as the ability to judge which pollutants are of greatest concern.

The need for air quality forecasting has been exacerbated by the recent energy emergencies in California, that are feared to be replicated elsewhere in due course. At this time, emission regulations are a major factor in decisions concerning what power plants to construct and which to utilize in specific circumstances. In the future, it is anticipated that new power plants will be constructed in areas where emissions will have the most benign consequences, as determined by the forecasting models to be developed in the present program. Moreover, the choice of which power plants to use in response to sudden increases in demand will be based on such forecasts. Such actions will not threaten the basis of the current regulatory system, but instead will constitute a modern methodology to work within the bounds imposed by regulations rather than ignore them.

The law and policy relevance. The regulatory system that has been evolved is now strangely limiting. The law is based on the assumption that specific regions have control over their own air quality. The error of this thinking became obvious centuries ago, when air pollution in France was dominated by emissions from England. In the mid 1970s, when the ozone and PM-10 standards were first being promulgated, it was shown convincingly that the air blowing into the city of Chicago was already often in violation of the proposed standards. The costs on society of imposing emission reductions locally when the cause of the problem is somewhere else have never been quantified. For the future, we must protect society against spending scarce resources unwisely. The job is one for scientists, not for regulators and lawyers acting without accurate scientific guidance.

Many cities have adopted systems for alerting the public to air quality problems. "Ozone alerts" are issued; firstly as an effort to educate the public and secondly to encourage remedial action at the personal level. Such actions might be to choose to use public transport instead of a private vehicle, or to delay mowing. In some cities, the issuance of alerts has been backed up by laws and regulations, such as to prohibit selected people from using machines that emit precursor chemicals, when an ozone alert is issued. So far, however, such enforcement has not worked well, because the forecasts do not yet display enough skill to warrant public acceptance of them. These forecasts are almost invariably based on statistics and regression models, which tend to miss in the prediction of extremes, yet it is the extremes that are the target of the short-term forecasting effort.

> ***The public and other agencies look to NOAA for environmental forecasts. Air quality is regulated by the EPA, but there is need for the regulations to be based on sound understanding.***

This work is relevant to the as yet unmet needs of several domestic and international policy instruments, including the following: **1. U.S. Clean Air Act.** Section 112(m) calls on the EPA *and* NOAA to assess the relative amounts and sources of atmospheric hazardous pollutant deposition to the Great Lakes, the Chesapeake Bay, Lake Champlain and coastal waters. **2. U.S. Clean Water Act.** Section 303(d) requires states to establish a total maximum daily load (TMDL) of pollutants to impaired waters to ensure that water quality standards can be attained. In conducting a TMDL analysis, the relative contributions from different sources – including those contributing via the atmosphere – must be quantified. **3. Great Lakes Water Quality Agreement**. This is an international agreement between the U.S. and Canada, last amended in 1987. Annex 15 requires research to better understand the mechanisms and effects of atmospheric deposition and to "...develop models of the intermediate and long-range movement and transformation of [airborne] toxic substances..." Annex 2 calls for the development and implementation of Lake-wide Management Plans for each of the Great Lakes. These plans must include an evaluation of sources responsible for loadings of critical pollutants, including contributions via the atmospheric pathway. **4. Binational Toxics Strategy.** This U.S./Canada agreement calls for an assessment of atmospheric inputs of toxic air pollutants to the Great Lakes, including efforts to inventory emissions of these toxic substances and model their loading to the Lakes. In addition, the relative impact of regional and long-range atmospheric transport is to be evaluated. **5. International POPs Treaty.** An international legally binding instrument dealing with a number of persistent organic pollutants is currently being negotiated under the auspices of the United Nations Environment Program. The protocol is being negotiated because of the recognition that "...many persistent organic pollutants are transported over long distances globally by air and sea and therefore exist in measurable and increasing concentrations far from the original site of origin..." ***For almost***

all pollutants of concern for the areas of relevance for any of the above regulatory efforts, technical analyses linking sources to receptors have not yet been done.

The Pieces. The overall problem is multiply scaled, stretching from local to regional concerns. Recent work has shown that a 2 km grid (or smaller) is required to resolve air quality differences occurring in coastal areas, and it is therefore likely that even smaller grids will be necessary for urban-scale work. Furthermore, the air quality goal imposes an additional need for this model to be fully integrated with a compatible regional simulation, so that the effects of background levels are properly taken into account.

NOAA's mesoscale modeling community is already working in a self-coordinated fashion to develop the simulations needed for the applications identified here. The report of an initial meeting of NOAA mesoscale modelers identified the goals presented here as a major justification for continued model development work. The community of modelers is already constructed. There is no additional organizational step that needs to be taken, save an acceptance by higher authorities that this community does indeed have its priorities right.

Several laboratories are already developing air quality codes to address specific situations (e.g. FSL, ETL, ARL, AL). There is need for these development programs to be harmonized, even though it is an obvious fact of life that there is no intention yet of producing any single model that will cover all aspects of the game for all users.

A key model development effort is "Models-3," a third-generation community model being constructed as a joint NOAA/EPA endeavor by scientists from the academic and federal research communities, assembled under the leadership of the NOAA group at Research Triangle Park. Models-3 is a "plug-and-play" framework, permitting different process modules to be integrated in a manner suited to specific applications. As it now exists, Models-3 operates on a parallelized computing system, and has been constructed in close collaboration with the HPCC program.

Earlier developments in the sequence leading to Models-3 contributed to much of the mesoscale modeling capability on which weather forecasting activities now rely. The MM-5 community model owes much of its development to the air quality modeling developments of earlier versions of Models-3. Now, the scientists working on completing Models-3 are looking to Eta and the new WRF models as the bases for future developments. However, Models-3 is unabashedly designed for full-blown attention to specific policy and/or assessment applications. It is not intended for the real-time forecasting application that is targeted here. Rather, it is viewed as the full-form supermodel from which simpler models suitable for forecasting will evolve.

Some first steps towards testing the ability to forecast using reduced-form models have already been conducted. A simplified ozone chemistry scheme has been coupled with transport and dispersion codes driven by the NCEP Eta model. The initial application has been for Texas, where state authorities are actively evaluating the utility of this new NOAA trial product. It must be emphasized that the purpose is to provide mesoscale background information for use as input to more local pollution forecasts. There is no intent to compete with the providers of these more local forecasts, but only to make their job easier.

Testing the Products. Selection of a target area for comparative model testing may well become a key issue. Research areas already under NOAA control (or influence, at the least) are being actively promoted. Current attention focuses on eastern Tennessee (the East Tennessee Ozone Study – ETOS) and the Canaan Valley. In ETOS, air quality data are being collected in an intensive manner with a high spatial density of stations, as is needed to test forecast model outputs. At Canaan Valley, measurement sites are currently being set up. In addition the Cooperative Air Surface Exchange Site (CASES) in Kansas offers a unique opportunity to advance understanding of the lower atmosphere in a highly instrumented environment. (The Argonne Boundary Layer Experiment is collocated with CASES, and provides a concentrated PBL monitoring infrastructure now available for exploitation.)

Collaboration with other entities (States, for example, as in the case of Texas) offers the opportunity to test the forecasts that are made. The involvement of an independent evaluating party has proved to be advantageous.

Steps already taken. The scientists involved in the Models-3 program took the early lead in promoting closer interaction among NOAA mesoscale modelers. A complete report of the first NOAA mesoscale modelers' meeting is now available, and a second meeting has recently been held. The emerging themes of these gatherings are increasingly oriented towards air quality forecasting. The science is ready, the scientists are excited, and the clients are waiting.

There are several different levels at which the science is currently progressing. Most work addresses the need for improvement on forecasting accuracy through refinement of the methods currently employed -- essentially based on a statistical description of the relationships between air quality and controlling meteorological variables that are then derived from standard weather forecasts. These methods have been shown to be quite limited in their forecast capabilities, since obvious determinants such as changes in emission rates of causative chemicals are not taken into account. However, these statistical methods are simple to use, require few computer resources, and do not interfere with the standard operations of weather forecasters.

At the opposite extreme in complexity is the use of a fully detailed chemical model coupled with an equally advanced meteorological forecast routine. Although clearly capable of addressing every one of the problematic areas of the statistical methodologies, the requirements for computer power are such that real-time implementation seems unlikely. This leads to the middle-of-the-road alternative that constitutes a focus for the research and development program that is addressed here.

The focus is to embed sufficiently advanced descriptions of air chemistry in the next generation of mesoscale forecast models, so as to enable air quality forecasts to be made with the same models as underpin standard forecast operations.

It is already a stated goal of the National Weather Service to provide air quality forecast guidance in the future. It is the present goal to develop the methodologies that are adequate to provide an acceptable air quality skill score, and to improve this in a graduated series of demonstration projects extending over several years.

Contemporary air quality forecast operations have been notorious in their poor performance. Without known exception, these have all been statistical. It is the present approach that continued reliance on statistical methods is no longer warranted. To do so would be to continue to impose small incremental improvements on a basic structure that is fundamentally flawed. The intent is to start from scratch, by introducing chemistry into mesoscale forecasting models and then simplifying the chemistry until an optimum between computing requirements, timeliness, and skill. This process has already been anticipated in the design of the progeny of Eta, MM5, and RAMS – the Weather Research and Forecasting model (WRF). The present purpose is to work directly with the related model developers and to optimize the air quality components that these modelers are currently anticipating.

The final product will not be designed to tell every citizen what his or her exposure will be, but instead to provide an areal foundation for more detailed predictions by experts with local experience and clients. It is intended that the product will be a federal service to a rapidly growing commercial sector of air quality forecast providers.

In 1995, ARL scientists (working with Australian and US University partners) provided trial ozone forecasts for Texas, using a Lagrangian model with embedded "lumped" chemistry. ("Lumped chemistry" relates to a system of chemical reactions in which chemicals are grouped so as to reduce the number of equations.) The results indicated periods during which predictions matched observations well, but also showed other periods when agreement was lacking. Scrutiny of the data indicated that the prediction of rainfall (or perhaps cloud cover) was a key consideration. In 1996, the experiment was repeated, but with an expanded set of chemical equations. Results were similar.

In parallel with this activity, work was starting on testing a fully Eulerian approach constructed on the basis of the ARL-developed Models-3/CMAQ system, at Research Triangle Park. This approach requires far more computer power than is associated with the Lagrangian methodology, far beyond contemporary computer capabilities within the National Weather Service, for example. The activity was then (and continues to be) seen as a continuing trial of an evolving product.

Various other tests of the two systems (Lagrangian from Silver Spring, Eulerian from Research Triangle Park) were conducted in the succeeding years.

The Houston Air Quality study conducted under the auspices of the NOAA Health of the Atmosphere program caused a disruption in the provision of ARL ozone forecasts for Texas, because the money provided by the State of Texas to permit the work to be conducted was terminated. At the same time, the East Tennessee Ozone Study (ETOS) was gathering momentum. In practice, the ETOS results were outstandingly useful, since they underlined the importance of addressing the situation of complex terrain. It is known that local wind direction is often a controlling factor for air quality. At this time, accurate prediction of wind direction in complex terrain seems beyond the grasp of available models. There is, therefore, considerable work to be done. One immediate suggestion has been to change the focus of the forecasting development effort, from trying to predict concentrations at a specific place and time to predicting, instead, the probability that concentrations will exceed some selected harmful level. It is thought that this latter approach might be the only way to handle the effects of complex terrain in a fashion that will permit a rewarding evaluation against data.

The experimental component – ETOS. Based on ozone profile measurements conducted at NOAA's ATDD laboratory during the summer of 1995 in collaboration with the University of Tennessee, ATDD has initiated an experimental measurement and forecasting program, the East Tennessee Ozone Study – ETOS. The program is designed to measure and forecast ozone concentrations for the region of the East Tennessee Valley. The original ETOS program has been expanded to include mid-regions of the Appalachian Mountain chain (MARRS). This program was predicated on the potential for significant economic and health impacts on the East Tennessee Valley and Great Smoky Mountain National Park from elevated ozone levels. The stated goal of the program is to develop an air-quality forecasting system for the Southern Appalachian mountains including the East-Tennessee Valley.

Increased recognition of the number of declared "unhealthy" days by the general public as well as local, State and Federal organizations (and in particular public interest groups such as the Tennessee Valley Energy Reform Coalition) has increased emphasis on providing the public with current and forecast levels of air quality - primarily related to ozone. The degradation of air quality in the Great Smoky Mountain Park has the potential for significant economic impact on the East Tennessee Valley. In 1998, the Great Smoky Mountain National park reported 44 days of unhealthy ozone conditions, in 1999, the number of days increased to 51.

NOAA/ATDD initiated ETOS in collaboration with The University of Tennessee and the National Park Service (Great Smoky Mountain National Park). This community partnership has grown to include Air Monitoring Departments for the States of Tennessee, Kentucky, South Carolina, and North Carolina and the Cherokee Indian Reservation. Recently, representatives from several regional National Forest Service Offices and the Tennessee Valley Authority joined the NOAA/ATDD lead science team.

The ultimate goal of ETOS is the development of a validated air quality forecasting tool for the Southern Appalachians which recognizes the complex nature of the ridge/valley topography. The program builds on long history of atmospheric chemistry developed through NOAA's Health of the Atmosphere Program (in particular, the HOA program identified that the emission of VOCs from vegetation is much greater than human produced emissions of these compounds in almost all areas of the southeastern U.S.). Although, this has significant impact on forecasting within the East Tennessee region, regional transport of ozone and regional emission sources of NOx play a dominant role in the overall ozone climatology of the region.

Results from ETOS'99 indicated a complicated pattern of regional transport across the Tennessee Valley superimposed on local influences of the major urban centers. Late July '99 and September '99 aircraft measurements demonstrated that roughly 75%-80% of the measured surface ozone concentrations could be attributed to inflow or background transport of material into the Valley. Air parcel trajectories generated with high resolution National Weather Service gridded model output meteorological fields and state-of-the-art air parcel trajectory models (coupled with the USEPA OTAG findings) attribute the industrialized Ohio River Valley as source region for the inflow of "background" ozone for many local episodes.

ETOS'99 used NOAA/ARL's HYSPLIT-4 model with chemical parameterizations as a test forecasting model. Model skill scores for both early and late summer were quite good; however, during the temperature extremes of July and August the model significantly under-predicted observed concentrations. The results indicate that better parameterization schemes are required for emission sources - natural, industrial and mobile.

NOAA/ATDD was able to deploy a number of ozone monitors to explore potential "within-grid" and model grid-to-grid differences. An analysis of the variability between observations leads to a general 5 ppb degree of accuracy which could be expected for any particular air quality forecast.

ETOS 2000 was significantly reduced in scale due to lack of support from NOAA. Plans to extend the model domain to include the Shenandoah Valley and the eastern-side of the Great Smoky Mountain National Park were eliminated from the scope of work. Research for the 2000 summer ozone season continued to focus on elevational differences in surface-measured ozone concentrations and potential long-term deposition at high elevations sites. Towards this goal NOAA/ATDD intends to assume responsibility for the Whitetop Mountain site (Southern Virginia), develop a western mountain site in collaboration with the Tennessee Valley Authority, and participate with the University of Tennessee at a southern Appalachian site to maintain a limited high altitude air monitoring network. These three sites, coupled with sites maintained by the National Park Service should provide an excellent platform to study regional transport of ozone into the Southern Appalachians. This network also maintains a NOAA interest in the region as future air quality initiatives are planned.

NOAA leadership of the ETOS program has been revitalized in FY 2001, with the involvement of several ARL Divisions and the emerging OAR interest in Air Quality Forecasting.

The North Carolina Supercomputing Center will be forecasting ozone levels across the region, concentrating especially on the focal period from 1 July to 31 August. The capabilities to be used rely on real-time use of the Models-3/CMAQ system developed by ARL at Research Triangle Park, NC.

The NOAA Twin Otter aircraft will be deployed from Knoxville airport to participate in ETOS-2001 for a two-week period in early August. The Twin Otter will conduct exploratory studies of ozone levels and air-surface exchange rates along transects over the east Tennessee valley.

The Modeling Outlook. ARL continues to advocate the development of two test beds for air quality forecasting, one in the humid east and another in the arid west. Each should have available supercomputer capability, with time available. Over the last four years, ongoing work has caused ARL's Divisions in Research Triangle Park, North Carolina, and Las Vegas, Nevada, to arise as the centers of preference. The centers of excellence are the North Carolina Supercomputing Center and the National Supercomputing Center for Energy and the Environment, respectively.

NCSC is a component of MCNC, a private, nonprofit corporation that was established in 1980 with the support of state leaders and the North Carolina General Assembly. In cooperation with its partners in industry, universities, and state government, MCNC has helped to establish a national reputation for North Carolina as a state that fosters research, education, and development of electronic and information technologies. NCSC provides computational science, modeling, and simulation expertise for the solution of industry problems and for academic collaboration. Available machines include a CRAY T916/4256, an IBM RS/6000 SP, and an SGI Origin 2400. In recent years, the collaboration that is of present relevance has been with ARL staff of the Atmospheric Sciences Modeling Division, at Research Triangle Park, NC. In addition, NCSC provides access to high performance computing resources for academic institutions and commercial partners.

NSCEE: The National Supercomputing Center for Energy and the Environment (NSCEE) is a national center focusing on computational science and engineering issues in modeling energy systems, the environment, and impact of human engineered energy systems on the environment. NSCEE is a component of the University of Nevada system, located on the campus of the University of Nevada Las Vegas. NSCEE has a long history of working on air quality projects with ARL and CIASTA staff. The computing resources include: a newly installed SGI/Cray Origin 2000, a Cray YMP/EL, a Convex C220, and a Sun ES5500 system. Each system has a minimum of eight processors and is accessible through the commodity Internet and Internet2. Aggregate peak computing power is greater than 16 billion 64bit floating point operations per second. A 5.4 trillion byte mass storage system provides long term nearline storage of user files. A user transparent data migration system automatically manages migration of files from online to nearline and back. NSCEE provides a wide range of engineering software (including mathematical libraries) for computational fluid dynamics, heat transfer, energy sciences, and scientific visualization.

UNLV and the NSCEE maintain versions of MM5, MINERVE, SCIPUFF, RAMS, and other meteorological models for simulating atmospheric flow and species transport. Researchers involved in this work have been using unique adaptive numerical techniques to model transport problems in the arid southwest, and it is anticipated that these methods will lend themselves well to the air quality forecasting goals of ARL. The methods developed by the UNLV/NSCEE team have been used recently in studies of airborne particles and the resulting visibility degradation, and of forecasting severe weather events and air quality in southern Nevada.

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